Kinematical contributions to the transverse asymmetry in semi-inclusive DIS

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We discuss the contributions of the transverse spin component of the target to the double-spin asymmetries in semi-inclusive deep inelastic scattering of longitudinally polarized electrons off longitudinally polarized protons.

In the studies of semi-inclusive charged and neutral pion production off a longitudinally polarized protons, the HERMES collaboration has observed a single target-spin asymmetry (SSA) [1]. This asymmetry could either result from twist-3 chiral-odd effects [2,3] and/or could be a reflection of the Collins effect [4]. Which of the two is relevant is an open issue. For a further understanding of "transverse asymmetry contribution" we discuss here the double-spin and double-spin azimuthal asymmetries, where those contributions are well defined.

A target with an anti-parallel (parallel) polarization with respect to the beam has a transverse spin component in the virtual photon frame which can only have azimuthal angle π (0) (Fig.1). The value of this transverse spin component is

$$|S_T| = |S| \sin\theta_\gamma, \tag{1}$$

where S is target polarization. The quantity $\sin\theta_\gamma$ is of order $1/Q$ and is given by

$$\sin\theta_\gamma = \sqrt{\frac{4M^2x^2}{Q^2+4M^2x^2}(1-y-\frac{M^2x^2y^2}{Q^2})}, \tag{2}$$

where M is the nucleon mass.

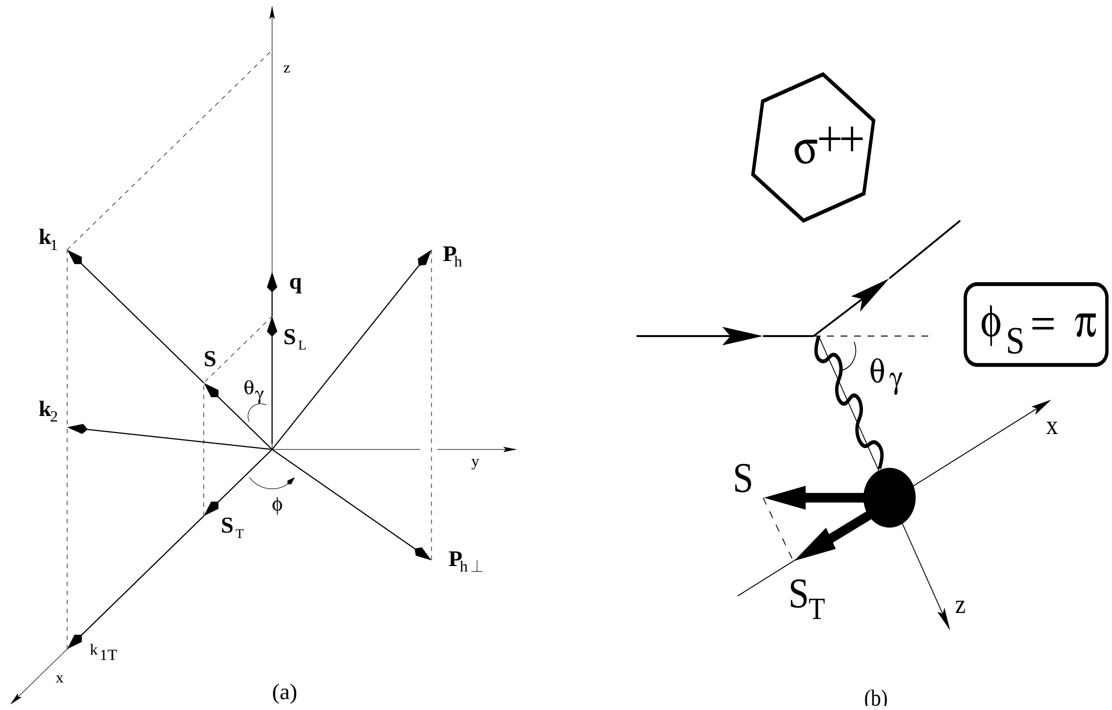

Fig.1. (a) – The kinematics of semi-inclusive DIS: k_1 (k_2) is the 4-momentum of the incoming (outgoing) charged lepton, $Q^2 = -q^2$, where $q = k_1 - k_2$, is the 4-momentum of the virtual photon. The momentum P (P_h) is the momentum of the target (observed) hadron. The scaling variables are $x = Q^2/2(P \cdot q)$, $y = (P \cdot q)/(P \cdot k_1)$, and $z = (P \cdot P_h)/(P \cdot q)$. The momentum k_{1T} ($P_{h\perp}$) is the incoming lepton (observed hadron) momentum component perpendicular to the virtual photon momentum direction, and ϕ is the azimuthal angle between $P_{h\perp}$ and k_{1T}. (b) – The definition of the azimuthal angle ϕ_S and the target polarization components in virtual photon frame.

First, we give an estimate of the $\cos\phi$ moment of the semi-inclusive DIS cross section, which is the following weighted integral of a cross section asymmetry [5],

$$A_{LL}^{\cos\phi} = \frac{1}{\langle P_{h\perp}\rangle} \frac{\int d^2P_{h\perp} |P_{h\perp}| \cos\phi \, (\sigma^{++} + \sigma^{--} - \sigma^{+-} - \sigma^{-+})}{\frac{1}{4}\int d^2P_{h\perp} \, (\sigma^{++} + \sigma^{--} + \sigma^{+-} + \sigma^{-+})}. \tag{3}$$

Here the subscript LL denotes the longitudinal polarization of the beam and target respectively, σ is a shorthand notation for $d\sigma^{eN\to ehX}/dx\,dy\,dz\,d^2P_{h\perp}$, the superscripts $++, --$ $(+-, -+)$ denote the helicity states of the beam and target respectively, corresponding to antiparallel (parallel) polarization[1]. Assuming 100% beam and target polarization and using the Wandzura-Wilczek (WW) approximation [6], where only the twist-2 distribution and fragmentation functions are used, i.e. the interaction-dependent twist-3 parts are set to zero, one obtains (for more details see Ref. [5])

$$A_{LL}^{\cos\phi} = \frac{4}{\langle P_{h\perp}\rangle} \frac{\Delta\sigma_{LL} - d\sigma_{LT}}{\sigma_{UU}}, \tag{4}$$

[1]It leads to positive $g_1(x)$.

where

$$\Delta\sigma_{LL} \overset{\mathrm{WW}}{\approx} -4\lambda_e \frac{S_L}{Q} \sqrt{1-y}\, M^2 g_1^{(1)}(x) z D_1(z), \tag{5}$$

$$d\sigma_{LT} \overset{\mathrm{WW}}{\approx} \lambda_e |S_T|\, (2-y)\, M \left[\int_x^1 du\, \frac{g_1(u)}{u}\right] z\, D_1(z), \tag{6}$$

$$\sigma_{UU} = \frac{[1+(1-y)^2]}{y}\, f_1(x) D_1(z), \tag{7}$$

being f_1 and g_1 (D_1) the well-known leading twist distribution (fragmentation) functions. Notice that the cross section $d\sigma_{LT}$ is positive but gives a negative contribution to the asymmetry (4) because of the dependence on the azimuthal angle ϕ_S: $\sigma^{++}(\sigma^{--}) = -d\sigma_{LT}$ and $\sigma^{-+}(\sigma^{+-}) = d\sigma_{LT}$ at $\phi_S = \pi(0)$ (see Fig.1 (b)).

It is important to point out that in the WW approximation the $\cos\phi$ asymmetry reduces to a kinematical effect conditioned by intrinsic transverse momentum of partons similar to the $\cos\phi$ asymmetry in unpolarized semi-inclusive DIS [7].

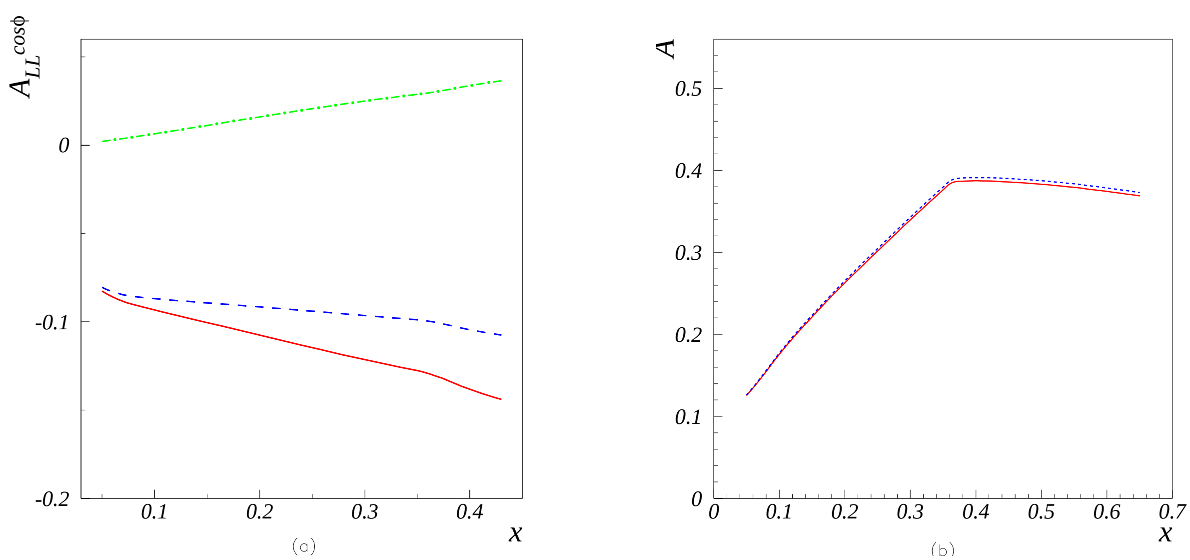

Fig.2. (a) – $A_{LL}^{\cos\phi}$ of Eq.(4) for π^+ production as a function of x. The dashed line corresponds to contribution of the $\Delta\sigma_{LL}$, dot-dashed one to $d\sigma_{LT}$ and the solid line is the difference of those two; (b) – Double-spin asymmetry, defined by Eq.(8), as a function of x. The full-curve corresponds to $\Delta\sigma_{LL}^{'}$ contribution and the dashed one is the total asymmetry.

In Fig.2(a), the asymmetry $A_{LL}^{\cos\phi}$ for π^+ production on a proton is shown as a function of x. The curves are calculated by integrating over the HERMES kinematical ranges [5]. As it can be seen, the WW approximation gives the large negative double-spin $\cos\phi$ asymmetry; the "kinematic" contribution coming from the transverse component of the target polarization is small (up to 25% at large x).

Let us now consider the following asymmetry

$$A = \frac{\int d^2P_{h\perp}\,(\sigma^{++} - \sigma^{-+})}{\int d^2P_{h\perp}\,(\sigma^{++} + \sigma^{-+})}, \tag{8}$$

which can be written as [2,8]

$$A = \frac{\Delta\sigma^{'}_{LL} + d\sigma^{'}_{LT}}{\sigma_{UU}}, \tag{9}$$

with

$$\Delta\sigma^{'}_{LL} = \lambda_e S_L\,(2-y)\,g_1(x)D_1(z), \tag{10}$$

$$d\sigma^{'}_{LT} \overset{\text{WW}}{\approx} 4\frac{M}{Q}|S|y\sqrt{1-y}\,x^2[\int_x^1 du\frac{g_1(u)}{u}]\,D_1(z). \tag{11}$$

In Fig.2(b), this asymmetry is given as a function of x. As it is shown, the contribution from the target transverse component is negligible.

Another possibility for studying the “kinematical” contributions is considering of $\sin(2\phi-\phi_S)$ – weighted asymmetry, $A_{LT}^{\sin(2\phi-\phi_S)}$, and its contribution to the target longitudinally polarized case.

In summary, the double-spin and the double-spin azimuthal asymmetries of semi-inclusive DIS of longitudinally polarized electrons off longitudinally polarized protons at twist-two level was investigated. A sizable negative $\cos\phi$ asymmetry is found for HERMES kinematics; the ‘kinematical’ contribution from target transverse component (S_T) to the $\cos\phi$ asymmetry, $A_{LL}^{\cos\phi}$, is small and that to the double-spin asymmetry, A, is negligible. Then, the measurements of SSA with transversely polarized target could help to understand the transverse asymmetry effects in the longitudinally polarized target case.

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